Asteroid Retrieval Mission Study Workshop – Part II

Preliminary Investigation of Human Near-Earth Asteroid (NEA) Mission Synergy with an Asteroid Retrieval Mission Concept Utilizing a 40 kW-class Solar Electric Propulsion (SEP) System

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Overview

Objectives

- Perform a preliminary investigation of the ability of a 40 kW-class Solar Electric Propulsion (SEP) system to provide pre-deploy capability for a human Near-Earth Asteroid (NEA) mission along with significantly increased return capability
- Identify a preliminary approach for a complete NEA exploration campaign that includes robotic precursor mission(s), human exploration, and Multi-ton Sample Return (MSR), and identify synergistic opportunities

Approach - examine several known candidate human mission targets as examples to provide estimates of combinations of delivered payload and return mass

- 2000SG344
  - Human mission Earth departure on 10/18/2029
  - Reasonable time period, easiest target, long synodic period (~30 years)
- 2004MN4
  - Human mission Earth departure on 4/9/2029
  - Reasonable time period, harder target, shorter synodic period ~(9 years), “public interest”
- 2010UJ
  - Human mission Earth departure on 10/5/2033
  - Fairly short synodic period (~12 years) , easier than 2004MN4, second longest departure window after 2000SG344, smaller NEA with poor Orbit Condition Code (OCC)

SEP Vehicle Assumptions

- **Power**
  - BOL Total: 40 kW
  - Available to Engines: 24 kW
- **Engines**
  - Specific Impulse: 2000 s
  - Engine Efficiency (Input to Jet Power): 50%
  - Duty Cycle: 95%
- **Mass**
  - Includes 50 kg of instrument mass and 300 kg of other spacecraft mass
  - Wet (w/ margin): 2592 kg
  - Total Propellant Available: 1000 kg
  - Other masses (anchoring/capture system, robotic arms, proximity, reaction control system (RCS), etc.) must be added to pre-deployed mass are required to be included in the payload mass

Human NEA Mission Pre-deploy Assumptions

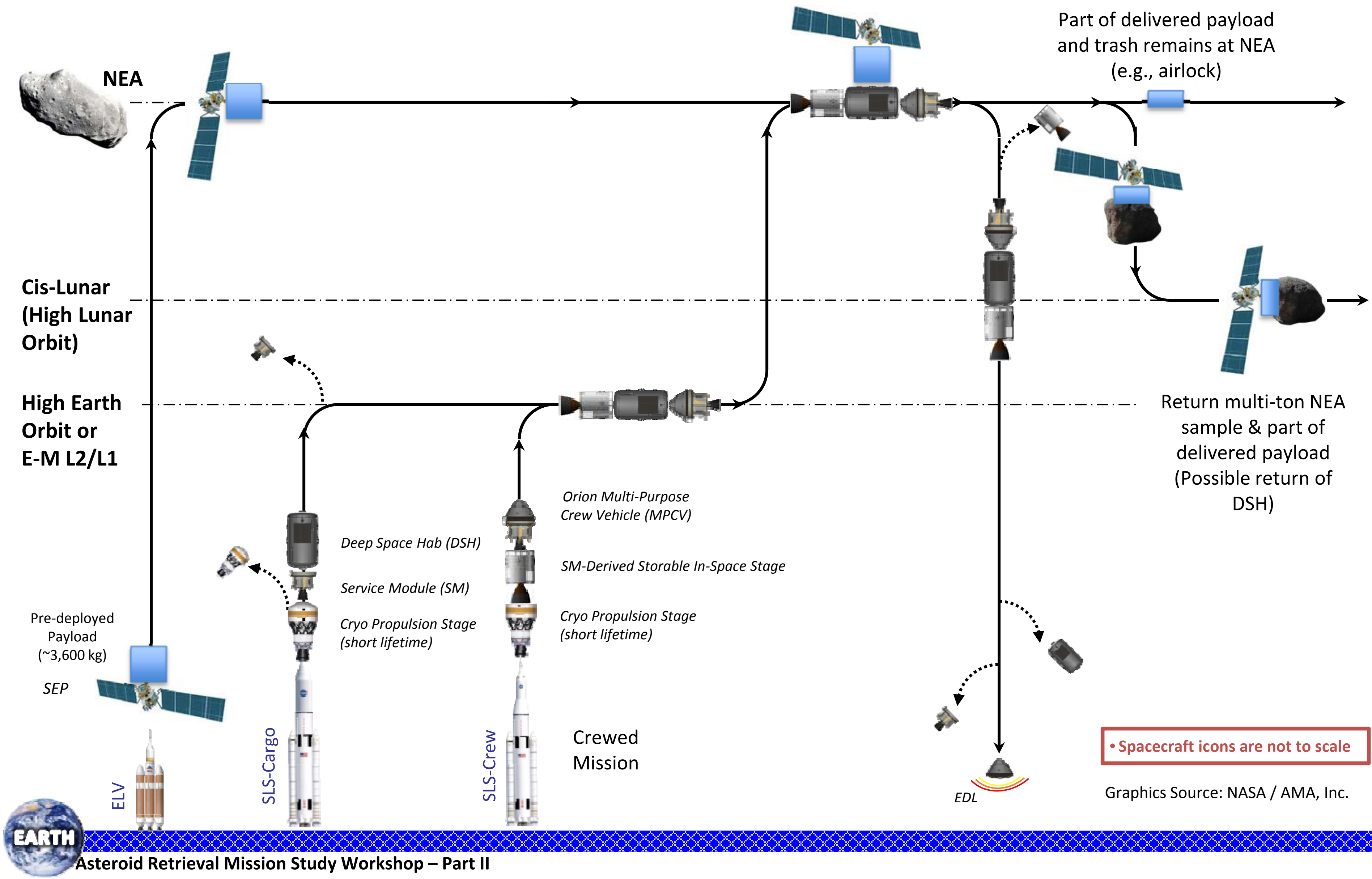
- **Only elements, systems, and logistics <u>not</u> required during the outbound and inbound mission segments can be pre-deployed**
  - Initial estimates identify that ~3,100 kg of element/logistics and 500 kg of destination payload could be pre-deployed
    - 1,900 kg external EVA airlock and 1,200 kg of "high-density" logistics
    - Additional destination specific payload beyond 500 kg is desirable
    - Robotic arms and anchoring/capture system, proximity RCS, etc. must be added to pre-deployed mass
    - Total pre-deploy mass of ~3,600 kg appears to be useful and sufficient
  - More detailed analysis (including abort scenarios) required to refine pre-deploy mass

- **Pre-deployed assets must be at NEA prior to crew departure from Earth and remain at NEA until after crew departure**
  - Assumed that LV provides escape C3 to minimize total pre-deploy duration as well as radiation and micrometeoroid and orbital debris (MMOD) exposure resulting from spiral from low-Earth Orbit (LEO)
    - Atlas V 551 – 6.074 t to C3 = 0
    - Delta IV Heavy – 9.306 t to C3 = 0
    - Estimate for Falcon Heavy – ~13 t to C3 = 0

NEA Target Selection Considerations/Drivers

- **ΔV (include splits – Earth departure, NEA arrival, and NEA departure)**
- **Human mission duration (~1 year or <u>less</u>)**
- **Human mission departure date (not too early & not too late!)**
- **Synodic period**
  - Human accessibility – longer is better for accessibility but worse for availability
  - Robotic precursor(s) for in-situ characterization and engineering validation need shorter periods (~10 years or less) to benefit the human mission
- **Orbit knowledge and remote characterization**
  - Need close approach observation opportunity or space-based survey to sufficiently reduce Orbit Condition Code (OCC) and provide basic remote characterization (size, spin rate, etc.)
- **Sufficient departure window**
  - Allow pre-deploy and conduct human mission
  - Depends on risk posture
    - What window is sufficient for human missions
    - Could send crew before pre-deploy arrives at NEA – there is always a chance of system, even after crew departure

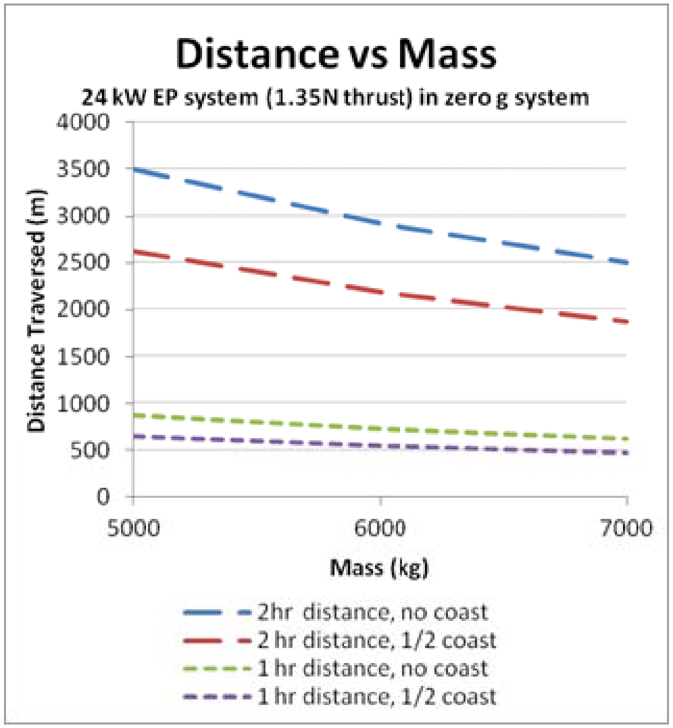
Notional NEA Human Mission Concept of Operations with Pre-deploy and Multi-ton Sample Return



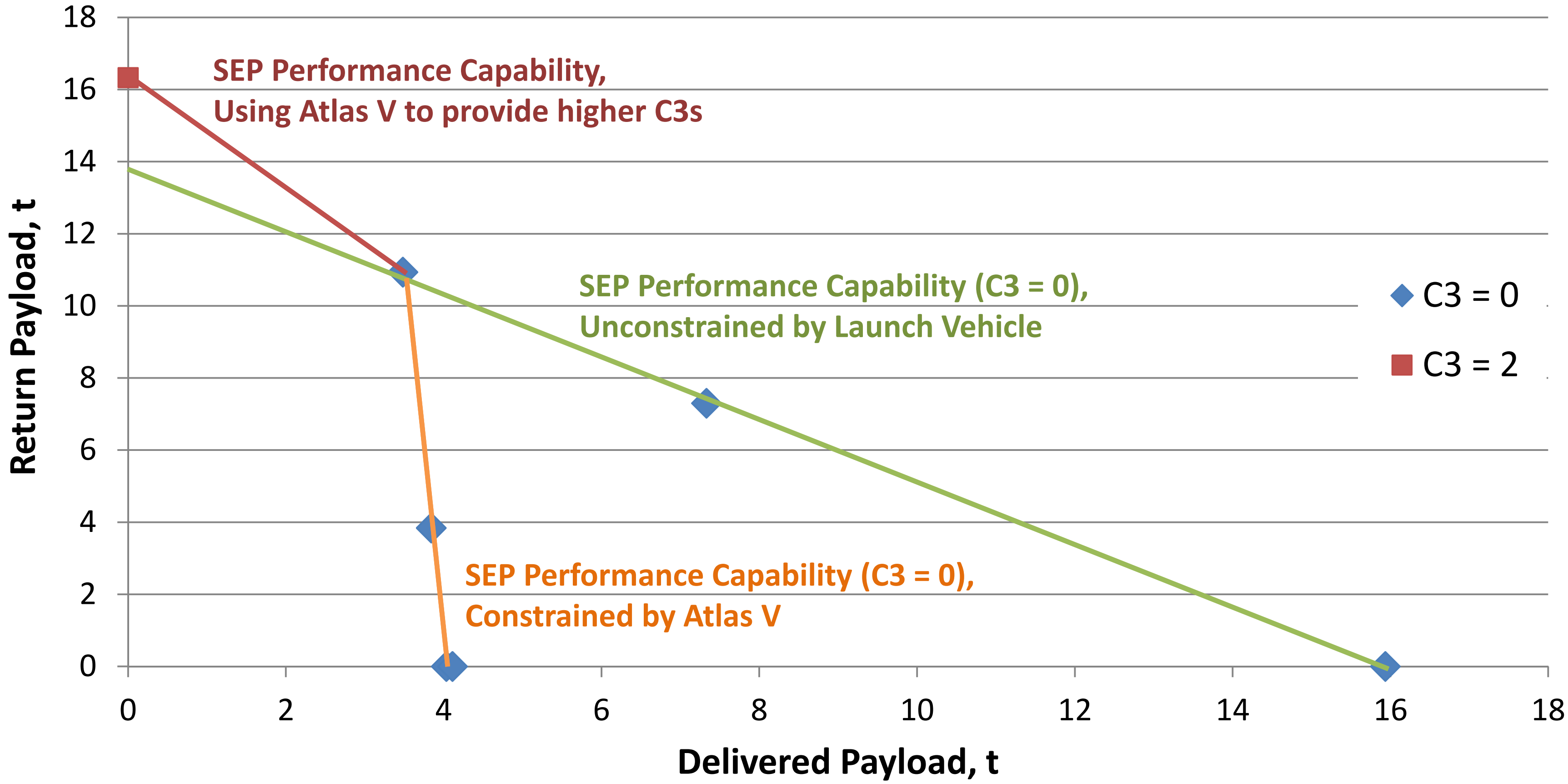
Possible Use of Pre-deployed Elements and SEP as an Excursion Vehicle

- **If SEP system can deliver ~4,000 kg of payload to the target NEA, this would likely be sufficient to provide elements and equipment to utilize the SEP as a single EVA excursion vehicle (airlock, robotic arms, anchoring system, etc.) and return sample carrier during human mission segment**
  - Crew would return ~100 kg of samples in Orion MPCV
  - SEP system would provide multi-ton sample return capability to cis-lunar space
  - Possible return of high-value mission elements to cis-lunar space (e.g., deep space hab) – needs to be assessed
- **Preliminary analysis indicates that using SEP for excursions from mission deep space hab to NEA appears feasible from a daily travel time/distance standpoint – local proximity operations needs further analysis**

Source:
NASA / AMA, Inc.



SEP Performance to 2000 SG344



2000 SG344 Cases

Atlas V — DropOff =PickUp

	Date	Mass (kg)
Earth Depart	5/19/2028	6074.05
NEA Arrival	5/28/2029	5703.87
NEA depart	6/5/2030	5703.86
L2 Arrival	1/27/2031	5434.98
EP Prop used		639.07
SEP wet (full)		2592.00
max usable prop		1000.00
Payload Out		3842.98
Payload back		3842.98
C3		0
LV Cap (Altas V)		6074.05

Atlas V — Max PickUp

	Date	Mass (kg)
Earth Depart	5/22/2028	2592.00
NEA Arrival	5/28/2029	2586.84
NEA depart	6/1/2030	18918.72
L2 Arrival	1/27/2031	17923.88
EP Prop used		1000.00
SEP wet (full)		2592.00
max usable prop		1000.00
Payload Out		0.00
Payload back		16331.88
C3		2.089333
LV Cap (Altas V)		5859.464

Atlas V — Max PickUp

	Date	Mass (kg)
Earth Depart	5/21/2028	6074.05
NEA Arrival	5/27/2029	5703.87
NEA depart	6/1/2030	13158.48
L2 Arrival	1/27/2031	12528.66
EP Prop used		1000.00
SEP wet (full)		2592.00
max usable prop		1000.00
Payload Out		3482.05
Payload back		10936.66
C3		0
LV Cap (Altas V)		6074.05

Crew TNI	10/18/2029
Crew Arrive	4/26/2030
Crew TEI	5/10/2030
Crew Return	10/10/2030

Unknow LV — DropOff =PickUp

	Date	Mass (kg)
Earth Depart	5/2/2028	18500.87
NEA Arrival	5/28/2029	18464.01
NEA depart	6/1/2030	18464.01
L2 Arrival	2/16/2031	17500.87
EP Prop used		1000.00
SEP wet (full)		2592.00
max usable prop		1000.00
Payload Out		15908.87
Payload back		15908.87
C3		2.092748
LV Cap (Altas V)		5859.113

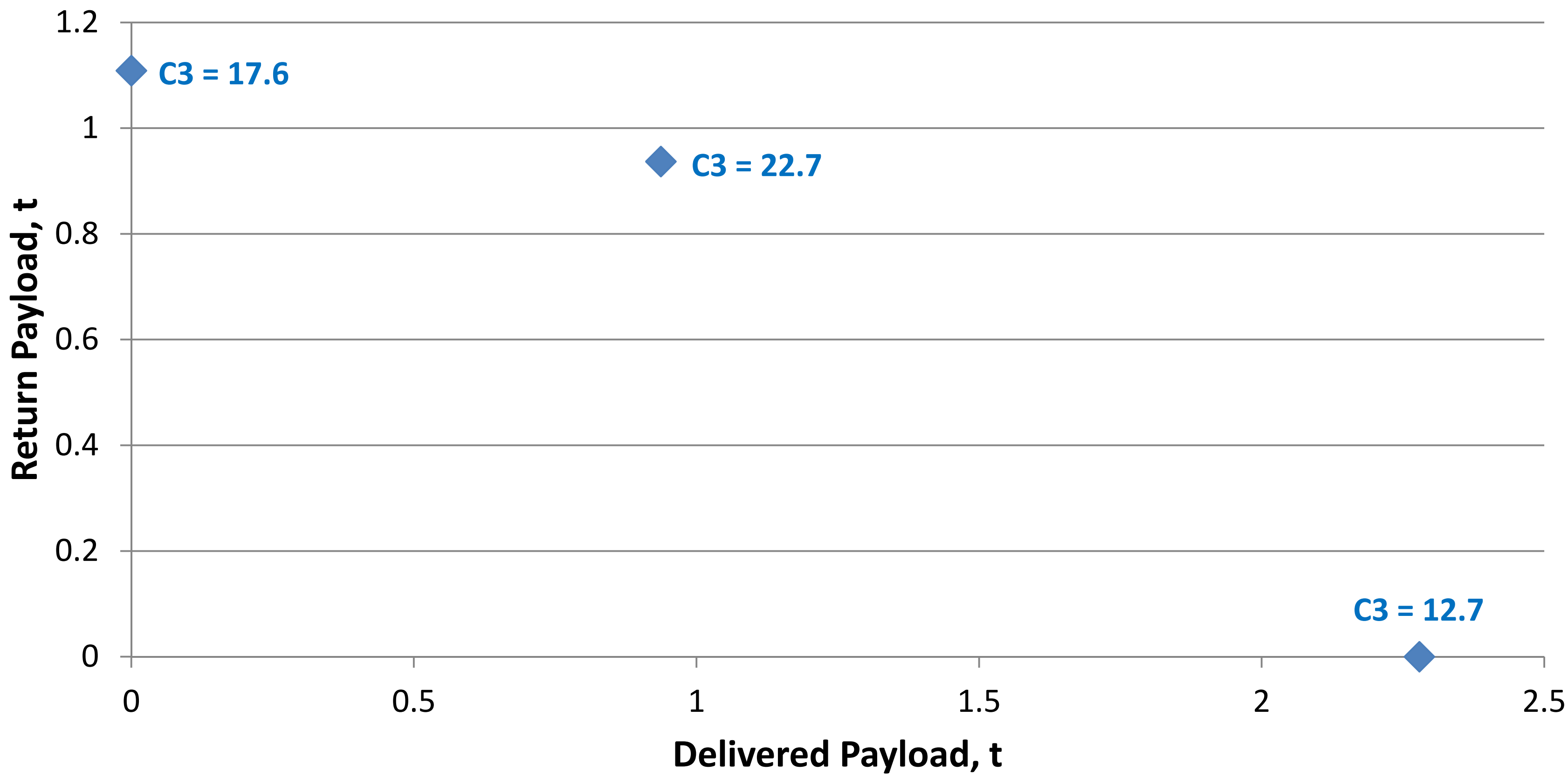
Unknow LV — DropOff =PickUp

	Date	Mass (kg)
Earth Depart	5/15/2028	9922.33
NEA Arrival	6/14/2029	9361.15
NEA depart	6/1/2030	9361.15
L2 Arrival	2/17/2031	8922.33
EP Prop used		1000.00
SEP wet (full)		2592.00
max usable prop		1000.00
Payload Out		7330.33
Payload back		7330.33
C3		0
LV Cap (Altas V)		6074.05

Unknow LV — Max DropOff

	Date	Mass (kg)
Earth Depart	5/16/2028	18527.72
NEA Arrival	7/14/2029	17605.70
NEA depart	6/13/2030	1669.98
L2 Arrival	1/26/2031	1592.00
EP Prop used		1000.00
SEP wet (full)		2592.00
max usable prop		1000.00
Payload Out		15935.72
Payload back		0.00
C3		0
LV Cap (Altas V)		6074.05

SEP Performance to 2004 MN4



2004 MN4 Cases

	Atlas V		Unknown LV		Atlas V		Atlas V	
	DropOff =PickUp		Max DropOff		Max DropOff		Max PickUp	
	Date	Mass (kg)	Date	Mass (kg)	Date	Mass (kg)	Date	Mass (kg)
Earth Depart	4/17/2028	3528.61	4/27/2028	7335.22	4/27/2028	4793.00	4/22/2028	2592.00
NEA Arrival	4/8/2029	3291.52	4/11/2029	6800.22	4/7/2029	4337.68	3/21/2029	2412.71
NEA depart	5/21/2030	3291.52	6/12/2030	2057.97	6/12/2030	2057.97	5/16/2030	3522.74
L2 Arrival	9/18/2031	2528.61	9/17/2031	1592.00	9/17/2031	1592.00	9/16/2031	2701.74
EP Prop used		1000.00		1000.97		921.30		1000.29
SEP wet (full)		2592.00		2592.00		2592.00		2592.00
max usable prop		1000.00		1000.00		1000.00		1000.00
Payload Out		936.61		4742.25		2279.70		-0.29
Payload back		936.61		0.00		0.00		1109.74
C3		22.68		17.72		12.72		17.55
LV cap (Atlas V)		3908.00		4335.00		4793.00		4348.00

Crew TNI	4/9/2029
Crew Arrive	5/28/2029
Crew TEI	6/5/2029
Crew Return	3/29/2030

2010 UJ Cases

	Unknown LV		AtlasV		Atlas V		Atlas V	
	DropOff =PickUp		Max DropOff		In Between		Max PickUp	
	Date	Mass (kg)	Date	Mass (kg)	Date	Mass (kg)	Date	Mass (kg)
Earth Depart	8/23/2032	6370.28	8/23/2032	4600.00	8/23/2032	4600.00	8/22/2032	2592.00
NEA Arrival	7/15/2033	6152.22	7/11/2033	4444.85	7/11/2033	4444.85	7/3/2033	2505.19
NEA depart	7/11/2034	6152.22	8/16/2034	1821.81	7/6/2034	6634.58	7/1/2034	7153.56
L2 Arrival	8/3/2035	5370.28	7/31/2035	1592.00	8/2/2035	5789.73	8/2/2035	6240.37
EP Prop used		1000.00		384.96		1000.00		1000.00
SEP wet (full)		2592.00		2592.00		2592.00		2592.00
max usable prop		1000.00		1000.00		1000.00		1000.00
Payload Out		3778.28		2623.04		2008.00		0.00
Payload back		3778.28		0.00		4197.73		4648.37
C3		14.81		14.81		14.81		14.81
LV cap (Atlas V)		4600.34		4600.34		4600.34		4577.20

Crew TNI	10/5/2033
Crew Arrive	1/18/2034
Crew TEI	1/26/2034
Crew Return	4/1/2034

Synergies of Asteroid Retrieval Mission with Human NEA Mission

- **Testing and validation of SEP and associated anchoring/capture hardware**
- **Move an asteroid to High Lunar Orbit (HLO) or possibly Earth-Moon L2/L1 Lagrange Points**
  - Provides useful activities in cis-lunar space and aids in preparing for human NEA mission
  - Could be the only way to meet 2025 goal of getting astronauts to an asteroid based on current budgetary constraints
- **Pre-deploy element, logistics, and destination payload for crew mission**
- **Provide precursor reconnaissance of human target (returning large boulder and regolith from human target)**
- **Provide resource redundancy (e.g., power and communications)**
- **Possible use of SEP as excursion vehicle and sample return carrier during human mission to provide MSR during crew mission**

Synergies of Asteroid Retrieval Mission with Future Human Exploration

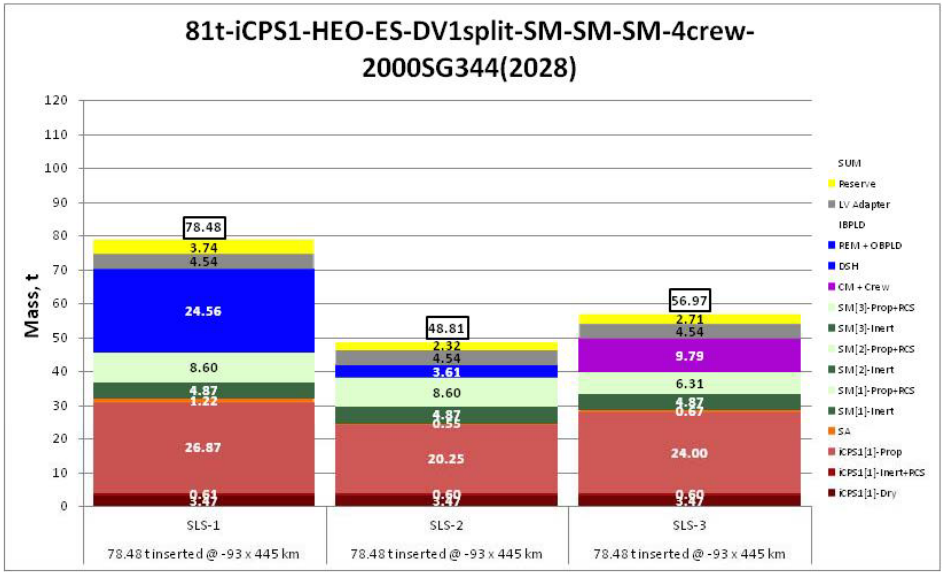
- **Process asteroidal material in cis-lunar space to provide radiation protection for future deep space missions and validate ISRU processes (e.g., cyclers)**
- **Planetary Defense (allows human exploration to continue!)**
  - Better understanding of impactors and operations/hardware maturity
  - Possible direct kinetic impact defense using collected small NEAs
- **Farther future… NEA returned to E-M L2/L1 (~10 m) could provide orbiting platform/counter weight for a lunar space elevator to allow routine access to/from lunar surface and also function as space resource processing facility**
  - Combined with lunar surface rail launch system for Earth return and low cost Earth-to-orbit delivery, this concept could make space resources profitable (e.g., rare metals) in terrestrial markets
  - Could provide a practical implementation of ISRU and logistics/propellant processing and delivery system for future human space exploration and settlement

Possible NEA Campaign Approach using 40 kW-class SEP

- **Improved ground-based NEA survey and improved follow-up observations (optical, radar, etc.) along with space-based NEA IR survey for improved orbit knowledge and remote characterization**
- **Multi-target robotic precursor to select NEA human target(s) – utilize SEP system to deploy multiple independent NEA probes (rendezvous/surface) – "Moving School Bus" concept**
- **Engineering Precursor to human target (larger NEA - 30+ m) and multi-ton sample return to cis-lunar space (high lunar orbit)**
  - Could be combined with multi-target robotic precursor (above)
  - Possible reuse of SEP (refuel)
  - Possible Phobos/Deimos MSR prior to robotic precursor NEA mission?
- **Human mission pre-deploy – elements (airlock, excursion vehicle, etc.), logistics and destination payload**
- **Mulit-ton sample return from human mission**
- **Independent mission to return single small NEA (1000 t class MSR)**

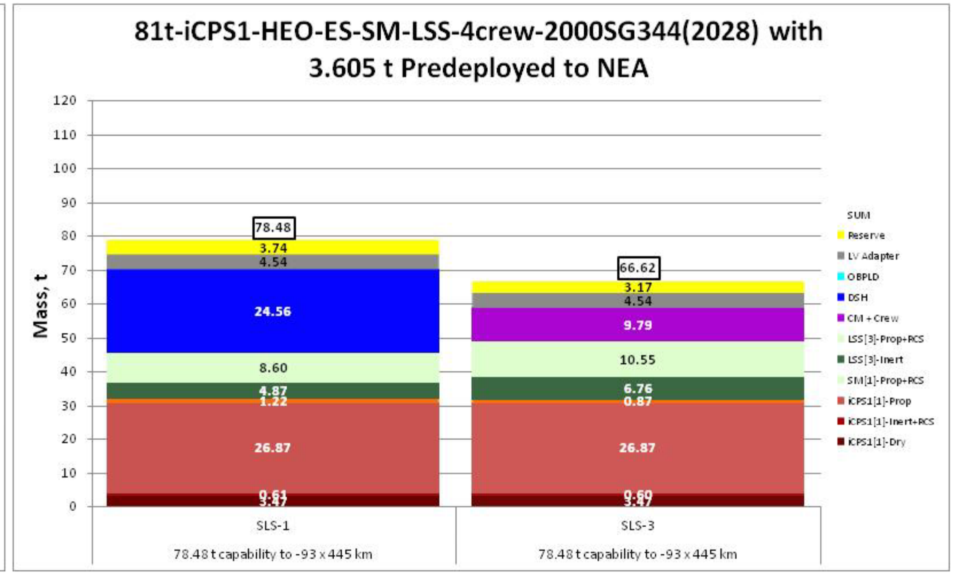
Example of Effect of Pre-deploy on Human NEA Mission – 2000 SG344

- **3 Launch SLS without pre-deploy**



- **2 Launch SLS with pre-deploy**

(Note: only human mission launches shown)



Conclusions

- **Preliminary analysis indicates that a 40 kW-class SEP system can provide pre-deploy and multi-ton sample return capability for NEAs that are accessible for human missions**
  - Improved SEP performance (e.g., additional propellant, higher I_{sp}, etc.) can increase capability and possibly provide return of high-value mission elements to cis-lunar space (e.g., deep space hab)
  - Additional LV C3 capability is desirable for higher energy targets
  - Further analysis is required to determine effect of pre-deploy for NEA targets other than 2000SG344
- **Many important synergies exist between an Asteroid Retrieval Mission and human missions to NEAs and future human space exploration and settlement**
- **Further work is required to develop campaign timeline for utilizing a 40 kW-class SEP for human missions to NEAs**